MICROFABRICATION OF PATTERN IMPRINTING

BACKGROUND OF THE INVENTION

Field of the Invention

5 The present invention relates to methods for imprinting micro-patterns, and relates in particular to a technique of evanescent(proximity)-field-assisted fabrication of two-dimensional micro-patterns of smaller dimensions than the wavelength of light.

10 ### Description of the Related Art

A typical example of fabrication techniques for making micro-circuit patterns on a semiconductor substrate is photolithography. In this technique, a photo-sensitive material (photo-resist) is coated on a substrate base, and a
15 reduced image of a masking pattern containing micro-circuit patterns is projected on the base by optical means to expose the photo-resist material. The degree of resolution achievable by photolithography is limited by light diffraction effects, and the minimum line width is ultimately limited by the wavelength
20 with respect to light. For this reason, it is necessary to use shorter wavelengths for fabrication of finer patterns. Currently, this is being achieved by using the g-line (436 nm wavelength) or the i-line (365 nm wavelength) of mercury lamp, or KrF excimer laser (248 nm wavelength) or ArF excimer laser
25 (193 nm wavelength), and the trend is towards the use of shorter wavelengths to meet the demand for finer line width.

In recent years, active research has been conducted on the use of evanescent field (proximity field) for fabrication of

1

micro-patterns. An evanescent field is an electro-magnetic field produced when light is transmitted through a transmissive object placed at a sub-wavelength distance of a light source. If an object having a micro-pattern surface structure, comprised

5   by high and low structures, is placed within a sub-wavelength of a light source, light is transmitted through the high structures of the structure, and evanescent fields are generated at these locations. Evanescent field diminishes exponentially as the separation distance increases beyond the wavelength of

10   transmitting light. Therefore, if a micro-pattern with height difference of the order of several tens of nanometers is coated with a photo-sensitive material and is placed at a sub-wavelength distance to an exposure light source, light is transmitted only through the high structures, thereby exposing only the coating

15   on high structures of the micro-pattern to the exposure light. In this technique, the line width of the exposed material is governed only by the fineness of the pattern placed in proximity of the light source, not by the exposure wavelength. Therefore, it is possible to produce micro-patterns exceeding the limit

20 · imposed by the exposure wavelength.

A known example of micro-pattern fabrication based on the evanescent field effect uses an optical fiber having one end sharpened to a sub-wavelength dimension, and a laser light is injected from the opposite end of the fiber. The sharpened end

25   is placed in contact with or in proximity to (at a sub-wavelength distance) a surface of a substrate base coated with a photo-resist film, then a proximity field is produced in the vicinity of the exposed region, and the light is transmitted through the

proximity field and the photo-resist film is exposed to the light. Therefore, by sharpening the tip to a sub-wavelength dimension, it is possible to expose a pattern scribed by a line width of a sub-wavelength dimension on the photo-resist film. The

5   photo-resist film is developed by photo-lithographical technology, then, using the exposed sections of the photo-resist film as the etch-masking, patterned surface of the substrate base is etched to remove the unprotected regions, thereby leaving behind micro-patterns of a sub-wavelength line width.

10   However, in this technique, the proximity field can only be produced at the tip of the optical fiber opposite to the base, therefore, the exposed pattern is a point. To apply this technique to the production of a two-dimensional pattern of some integrated circuit device, it is necessary to scan the tip in

15 a pattern of the circuit, so that it not only consumes a vast amount pattern-making time but also leads to the need for a complex tip-driving apparatus. Therefore, this technique is considered impractical.

        For these reason, there have been attempts to produce

20 micro-patterns using a mask that has a proximity field exposure pattern and transferring the two-dimensional pattern to a substrate base. For example, a prism made of a light transmissive material such as glass and the like is prepared and a photo-mask, having a proximity field exposure pattern of

25 sub-wavelength dimensions, is attached to the bottom surface of the prism. Light is injected into the prism at such an angle that it is totally reflected at the bottom surface of the prism. Next, a substrate base coated with a photo-resist film is placed

at a sub-wavelength distance of a proximity exposure pattern so that an evanescent field is produced and a two-dimensional pattern, conforming to the proximity exposure pattern, is exposed on the photo-resist film. In this process, an optical system for injecting a laser beam from an inclined surface of a prism is used, and the incident laser beam is totally reflected at a plane having a proximity field exposure pattern; and then it is transmitted to outside through another inclined surface. A photo-resist film surface of a substrate base is made to contact closely with the proximity field exposure pattern, so as to generate an evanescent field to propagate exposure light along the exposure pattern, and thereby producing micro-patterns having line widths of sub-wavelength dimensions.

The method utilizing the evanescent field described above enables to produce a two-dimensional micro-pattern having line widths less than the wavelength of the exposure light on a photo-resist film of a substrate. However, the method requires that the incident beam be aligned with the inclination angle of a prism, and the optical system is necessarily complex. Also, the exposure pattern section can only accept a small exposure area. And, because the incident light is at an angle to the proximity field exposure pattern, the depth of imprinting is shallow, and because the exposed area increases quickly along the beam line, it is difficult to expose a structure having high aspect ratios on the photo-resist film.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide an optical imprinting apparatus and method for producing a two-dimensional pattern, having line widths less than the wavelength of an exposure light, economically using a simple method and a low cost device.

It is another object of the invention to provide an imprinting method for imprinting two dimensional micro patterns with high aspect ratio.

In order to achieve the above object, there is provided an apparatus, which comprises a waveguide; a proximity field exposure pattern firmly fixed to a section of the waveguide; and a light source for injecting a light into the waveguide.

According to the present invention, by placing a substrate surface close to the proximity field exposure pattern, a portion of the light propagating in the waveguide is transmitted through an evanescent field to expose the substrate surface. Therefore, a compact apparatus having a waveguide having a proximity field exposure pattern and a light source is provided, which is much more compact compared with the conventional stepper device, and is much more economical. Because the waveguide can be made in a flat shape, by combining with a compact semiconductor laser and the like, the overall imprinting apparatus can be made quite compact.

An optical imprinting apparatus is comprised by a light source; and an exposure-mask having a proximity field exposure pattern for radiating an exposure light output from the light source on a photo-sensitive material through an evanescent field;

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wherein the exposure-mask is provided integrally with the light source.

The apparatus having an integral light source and the proximity field exposure pattern can provide a very compact apparatus, and can eliminate complex optical systems required in the conventional optical systems and produce micro-patterns of sub-wavelength dimensions.

A method for evanescent-field-assisted imprinting is comprised by the steps of: placing a proximity field exposure pattern on a waveguide or on a portion of a light source; aligning a fabrication object having a photo-sensitive film in proximity of the proximity field exposure pattern; injecting a light from the waveguide or the light source into the proximity field exposure pattern so as to imprint the proximity field exposure pattern on the photo-sensitive material by means of an evanescent field formed between the proximity field exposure pattern and the photo-sensitive film.

Because the proximity field exposure pattern is extremely close to the photo-sensitive material, micro-patterns are imprinted by the evanescent field effect to imprint two dimensional patterns using a simple apparatus. Direct use of the light source enables total reflection in a simple manner and a large area can be exposed very uniformly to provide a very effective process.

An exposure-mask for imprinting micro-patterns on a mask base is made in cooperation with an evanescent field generated by exposure light output from a light source, wherein the mask base is transmissive to the exposure light and is provided with

micro-patterns comprised by high structures and low structures of sub-wavelength dimensions with respect to a wavelength of the exposure light, and the low structures are embedded with a material of low transmissivity to the exposure light.

5   The proximity exposure enables micro-patterns to be exposed on a photo-sensitive material, and the low structures to be filled with a low transmissivity material, so that there is no light leaking from such regions of the patterns. The evanescent fields are produced only on the high structures, and a high contrast
10   (large height differences in the micro-pattern) can be produced in the pattern.

It is preferable that the low transmissivity material be a metallic substance. Such a structure can be produced by vapor deposition or sputtering of a metal film, followed by chemical
15   mechanical polishing to flatten the surface of the photo-sensitive material to produce an excellent photo-mask.

The low transmissivity material may be produced by ion exchange. It is also preferable that fabrication of the mask base is performed by fast atomic beams.

20   A method for making an exposure-mask having a fine pattern is comprised by the steps of: applying a photo-sensitive coating on a mask base made of a material transmissive to exposure light; fabricating micro-patterns on the photo-sensitive coating using electron beams or X-ray beams; and irradiating with a fast atomic
25   beam using the micro-patterns fabricated on the photo-sensitive film as exposure-mask; thereby imprinting micro-patterns on the mask base.

Micro-patterns can be produced on quartz glass or other transmissive materials together with a photo-sensitive coating and exposure by electron beam or X-rays. Thickness of the photo-sensitive material should be up to twice the size of the

5   micro-patterns. FAB is linear and free of charge accumulation so that insulation materials can be fabricated with micro-patterns of high aspect ratios. Parallel plate type FABs are preferable for use here. Also, it is noted that this technique is also applicable to the pattern dimensions of larger than

10   wavelength of the light.

A method for imprinting micro-patterns on a substrate base is comprised by the steps of: applying not less than two layers, including an upper layer of a photo-sensitive film having a thickness dimension of less than the wavelength of exposure

15   light; placing an exposure-mask having proximity patterns in contact with or in proximity of the photo-sensitive film at a sub-wavelength distance so as to generate an evanescent field and expose the proximity patterns on the photo-sensitive film; developing exposed proximity patterns by photo-processing to

20   produce a first etch-mask; fabricating a lower surface of the substrate base using the first etch-mask to produce a second etch-mask comprised by the lower film; and imprinting proximity field exposure patterns on the substrate base using the second etch-mask.

25   It is again demonstrated that the evanescent field effect promotes production of sharp micro-patterns. The depth of patterns produced by this technique is shallow, and the exposed

areas are dispersed quickly along the depth direction. Therefore, thin or film is able to perform precise fabrication.

A method for imprinting micro-patterns on a substrate base is comprised by the steps of: applying a first coating of a photo-sensitive material on the substrate base to a thickness less than a wavelength of an exposure light; placing an exposure-mask having a proximity field exposure pattern in contact with or in proximity of the proximity field exposure pattern at a sub-wavelength distance; exposing the coating through the exposure-mask using the exposure light through an evanescent field and developing by photo-processing to produce first imprinted patterns on the first coating; applying a second coating on the first imprinted pattern of the photo-sensitive material; dissolving the first coating to liftoff the first imprinted patterns, thereby leaving second imprinted patterns formed by the second coating; and fabricating the substrate base using the second imprinted patterns as etch-mask to produce micro-patterns on the substrate base.

Using such an exposure-mask, thick film as a second coating can also be imprinted to produce imprinted micro-patterns. Thick film has excellent tolerability so that high aspect structures can be produced readily by using the etch-mask technique with thick films.

It is preferable that the thickness of the first coating is essentially the same as a minimum dimension of the proximity field exposure pattern. It enables sharp imprinting of minimum dimensions. It is preferable that the fabrication of the substrate base or an exposed lower layer is performed using a

fast atomic beam. FAB has highly linear etching property and free from charge accumulation so that micro-patterns of high aspect ratios can be produced efficiently.

An exposure-mask for evanescent-field-assisted imprinting having a proximity field exposure pattern of sub-wavelength dimensions is fabricated on a transmissive material, wherein the proximity field exposure pattern is produced by imprinting a master proximity field exposure pattern provided on a mother mold.

This technique is suitable for mass production of proximity field exposure patterns at low cost. It can eliminate the necessity for expensive original mask for evanescent field assisted imprinting which can be applied to the production of LSI circuits.

It is preferable that the mother mold is a metal mold.

Metal mold can easily be detached from glass or resins so that the mask can be preserved well. Also, metals are excellent for producing micro-patterns and for imprinting purposes.

A method for making an exposure-mask is by preparing a mother mold having a pattern; pouring a transmissive material in a molten state into the mother mold; cooling and detaching a solidified pattern from the mother mold, thereby producing an imprinted proximity field exposure pattern.

It is therefore possible to use low cost materials such as plastics, resins (PMMA) to produce micro-patterns, and the cost of making exposure-mask is reduced.

It is preferable that detaching from the mother mold is based on differential thermal expansion effects of materials constituting a mother mold and an imprinted pattern.

This separation technique is enhanced by a metal mold when glass and resins are used for making duplication mask.

It is preferable that the mother mold is pre-coated with a soluble film, which is dissolved when detaching a solidified pattern from the mother mold.

This technique is cost effective and can easily be applied to many applications when making duplication mask.

The base may be coated with SiO_2 followed by a resist film to make a fine pattern, which is used as mask to etch the SiO_2 film with FAB, and a metal film is further deposited, and the SiO_2 film is removed by dissolving in HF solution. The metal film can be used as a mother mold.

A method for imprinting micro-patterns on an imprint base by preparing a pattern template having a fine structure, coating a semi-solid material on the pattern template; pressing the semi-solid material on the pattern template to produce a duplicated pattern of the fine structure; irradiating the duplicated pattern to produce the imprint base having the micro-patterns.

This technique eliminates the need for alignment of micro-patterns and expensive optical equipment is not needed, so that low cost mass production of micro-patterns is made possible. Also, it is noted that this technique is also applicable to the pattern dimensions of larger than wavelength of the light.

It is preferable that the pattern template is a roller having the fine-structure fabricated on an roller surface, and the fine-structure is duplicated on an imprint base by press rolling on a semi-solid material.

5   This technique is quite adaptable and can be applied to a curved surface.

It is preferable that the pattern template is a flexible material disposed away from a semi-solid imprint base, which is roll pressed by a roller template to intimately contact the roller

10   template and thereby imprinting the micro-patterns on the semi-solid imprint base.

This technique is applicable to non-flat surfaces to imprint micro-patterns accurately.

A method for imprinting micro-patterns on an imprint base

15   by preparing a pattern template having a fine structure comprised of high and low structures, pouring a molten material on the pattern template; cooling the molten material on the pattern template; detaching a solidified pattern to produce a duplicated pattern of the fine structure to produce the imprint base having

20   the micro-pattern.

This technique allows pouring of molten material to produce an imprint base having micro-patterns so that it is effective for low cost mass production.

A method for fabricating micro-patterns on an imprint base

25   is by applying a photo-resist layer coating on a pattern template; scribing a fine structure on the photo-resist coating by means of electron beams or X-ray beams and developing by photo-processing to fabricate etch-mask; irradiating with a fast atomic

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beam through the etch-mask to produce an imprint base having the fine structure duplicated thereon.

Electron or X-ray beams do not present diffraction problems so that micro-patterns can be produced on resist film easily, which is used as etch-masking for FAB to produce micro-patterns of high aspect ratios on imprint bases. Also, it is noted that this technique is also applicable to the pattern dimensions of larger than wavelength of the light.

A method for imprinting on an imprint base for LSI devices is by preparing an exposure-mask having a fine structure of sub-wavelength dimensions; exposing a substrate base of a semiconductor material coated with a photo-sensitive material through the exposure-mask in an evanescent field so as to imprint the fine structure on the LSI device base.

This method allows micro-patterns to be imprinted on photo-resist film easily and effectively. The exposure apparatus is comprised only by a mask having a proximity field exposure pattern, eliminating the need for complex optics. The apparatus cost is low and the production cost is low.

A method for imprinting micro-patterns on LSI devices is by preparing a pattern template having a fine structure of sub-wavelength dimensions; pressing the pattern template on a semi-solid material coated on a substrate base of a semiconductor material so as to imprint the fine structure on a surface coating; and etching the surface coating using imprinted patterns as etch-mask to produce the LSI devices.

Imprint template in this case corresponds to normal photo-mask used in fabrication of LSI devices, but the template

has micro-patterns which can be replicated readily by pressing on semi-solid materials. The imprinted patterns are used as etch-mask for FAB to produce micro-patterns of high aspect ratios on an LSI base.

5   An optical data recording medium contains recorded signals fabricated using a method of evanescent-field-assisted fabrication.

Signal bits produced by the evanescent field effects has micro-patterns of sub-wavelength dimensions, so that the density 10 of recording can be increased in quantum steps.

An optical data recording apparatus is comprised by: a recording medium having micro-patterns of sub-wavelength dimensions, with respect to signal light, having different transmissive and reflective properties; a light source for signal 15 light; and a detection section disposed opposite to a patterned surface of the recording medium.

The data recording medium can store significantly more data compared with similar conventional recording medium. The apparatus is a stationary recording apparatus of an extremely 20 overall compact size. No moving parts are involved in such an apparatus, so that potential wear is reduced and accompanying operating noise is minimal.

An magnetic-optical recording head is comprised by an optical fiber having a sharpened tip of a sub-wavelength 25 dimension with respect to signal light, and a magnetic field generation coil for magnetizing a magnetic layer disposed in proximity of the sharpened tip in association with the magnetic-optical recording head.

Signal transfer is carried out through the evanescent field at the nano-tip of the fiber, so that data transfer, in association with the magnetic field produced in the head and storage medium of micro-sized dimensions, to lead to a quantum

5   increase in data density and performance speeds.

The above and other objects, features, and advantages of the present invention will become apparent from the following description when taken in conjunction with the accompanying drawings which illustrate preferred embodiments of the present

10   invention by way of example.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view showing a concept of an embodiment of the photo-driven imprinting apparatus.

15   Figures 2A-2C are schematic diagrams of light sources and waveguides.

Figure 3 is a side view of exposure device using an evanescent field.

Figures 4A, 4B are illustrations of the evanescent field

20   effect to show, respectively, a profile of a proximity field exposure pattern, and the dependence of the transmission characteristics of light on the distance of separation between high points of the proximity field exposure pattern and the photo-resist film.

25   Figure 5 is a schematic diagram of another embodiment of the photo-driven imprinting apparatus.

Figure 6 is a schematic diagram of a variation of the embodiment shown in Figure 5.

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Figure 7 is a schematic diagram of still another variation of the embodiment shown in Figure 5.

Figure 8 is a schematic diagram of still another variation of the embodiment shown in Figure 5, which produces a light generated by electron beam scanning of a photo-activated gas.

Figure 9 is a schematic diagram of still another variation of the apparatus in Figure 8, which produces a light generated by electron beam scanning of light-generating particles.

Figure 10 is a variation of the apparatus shown in Figure 9.

Figures 11A-11F are illustrations of steps for making a photo-mask having a proximity field exposure pattern.

Figures 12A-12E are a variation of the steps shown in Figures 11A-11F.

Figures 13A-13E are a variation of the steps shown in Figures 11A-11F.

Figures 14A-14E are illustrations of the steps for micro-pattern imprinting method in an embodiment.

Figures 15A-15F are illustrations of the steps for a variation of the method shown in Figure 14A-14E.

Figures 16A-16F are illustrations of the steps for another variation of the method in Figure14A-14E.

Figures 17A-17D are illustration of the steps for making a photo-mask in an embodiment.

Figures 18A-18D are illustrations of the steps for making a mother mold in an embodiment.

Figures 19A-19E are illustrations of the steps for making a duplicated mask in an embodiment.

Figures 20A-20E are illustrations of the steps for making a mother mold in a variation.

Figures 21A-21D are illustrations of the steps for a method of micro-pattern imprinting in an embodiment.

5   Figures 22A-22D are illustrations of a variation of the method shown in Figures 21A-21D.

Figures 23A-23D are illustrations of a variation of the method shown in Figures 21A-21D.

Figures 24A-24D are illustrations of a variation of the
10   method shown in Figures 21A-21D.

Figures 25A-25D are illustrations of a variation of the method shown in Figures 24A-24D.

Figures 26A-26D are illustrations of a variation of the method shown in Figures 25A-25D.

15   Figures 27A-27E are illustrations of the steps for a method of micro-pattern imprinting in a variation.

Figures 28A-28E are illustrations of the steps for a method of micro-pattern imprinting in a variation.

Figures 29A-29D are illustrations of the steps for a method
20   of micro-pattern imprinting in a variation.

Figures 30A-30E are illustrations of the steps for a method of micro-pattern imprinting in a variation.

Figures 31A-31D are illustrations of the steps for a method of micro-pattern imprinting in a variation.

25   Figures 32A-32D are illustrations of the steps for a method of micro-pattern imprinting in a variation.

Figure 33 is a cross-sectional view showing a cell structure of DRAM in a semiconductor device.

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Figures 34 is illustration of a variation of the DRAM shown in Figure 35.

Figures 35A-35D are illustrations of the st ps for a method of making a master disc for producing recorded medium used in optical disc apparatus.

Figures 36A-36E are illustrations of the steps for a method of making an optical recording medium using an imprinting body.

Figure 37 is schematic diagram of a reading head in an optical disc apparatus in the embodiment.

Figure 38 is a schematic diagram of a variation of the reading head in Figure 37.

Figure 39 is a schematic diagram of another variation of the reading head in Figure 37.

Figure 40 is schematic diagram of an optical recording device in an embodiment.

Figure 41 is schematic diagram of a reading head in an optical-magnetical disc apparatus in the embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows an embodiment of the photo-driven imprinting apparatus. A proximity field exposure pattern (shortened to proximity pattern hereinbelow) 12 is fixed to a section of a waveguide 11. A light source 13 is connected to an input surface 11a of the waveguide 11, and a light input into the input surface 11a propagates through the waveguide 11. The waveguide 11 is a flat plate, and its upper and lower surfaces are treated so as to obtain total reflection between the two surfaces. For example, all the surfaces, excepting both sections of the input

surface 11a and the proximity pattern 12, are coated with a metal film. The waveguide 11 is made of quartz glass or a light-transmissive material such as polyimide, and excepting the input/output surfaces, the surfaces are coated with a metal film

5 such as Cr, Al, Ag or Au. Therefore, an incident light beam entering from the input surface 11a are trapped inside the transmissive material of the waveguide 11.

Instead of coating all the surfaces with a metal film, the optical transmissive material may be made of a core and a cladding

10 to produce a total reflection condition. Total reflection may be produced by constructing the waveguide 11 with a transmissive material, and its lateral surfaces are coated with a metal film, and the upper and lower surfaces may be exposed to the atmosphere. In any case, the important conditions are to arrange the waveguide

15 so that the light input from the input surface 11a is trapped within the waveguide 11, and when an object is placed in proximity of the proximity pattern 12, an evanescent field is produced on the surface of the object, and the trapped light energy is released and the light is propagated therethrough.

20 Figure 2A-2C show specific arrangements of the light source 13. A fiber bundle 13a is used to transmit light emitted from a mercury lamp or a laser beam source, and the light is focused through a lens 17 and is injected into one end of the fiber bundle 13a and output from the opposite end thereof to enter through

25 the input surface 11a of the waveguide 11, as shown in Figure 2A. In this case, the light source may emit laser light, mercury lamp light or white light. Figure 2B shows a semiconductor laser 13b for generating light beam of spectrum from red to blue from

the surface thereof, which propagate at right angles to the surface thereof. Therefore, it is suitable for the light beam to be input into the waveguide 11 from the surface 11a.

Figure 2C shows a waveguide 21 having fluorescent particles
5   of Mg, Ti or It in the waveguide 21. Such fluorescent particles generate a light having a wavelength according to the characteristics of the nature of the particle, for example, when the particles are excited by white light input from the fiber bundle 13a. Namely, when the particles are excited by the
10 injected white light, then the particles emit a light beam having a wavelength. This device can thus acts as a wavelength converter, and enable to use low cost white light to generate a light of a wavelength suitable for use in the evanescent field. In general, a photo-sensitive material responds to a particular
15 wavelength so that wavelength conversion is required to select the most suitable wavelength for a particular photo-sensitive material. Also, it is preferable to use shorter wavelength because shorter wavelengths exhibit less dispersion of light. Therefore, a wavelength conversion device enables to utilize low
20 cost white light to produce a particular wavelength suitable for a particular photo-sensitive material.

Also, it is desirable that the waveguide 11 be made of a flexible material. Such a flexible material enables to fabricate micro-patterns of narrower line widths than the
25 wavelength of exposure light on a curved surface by using evanescent field effect. For example, light-transmissive material of polyimide offer sufficient flexibility for imprinting micro-patterns on a curved surface.

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A waveguide may be made of a SiO_2 film deposited on a silicon wafer. Such SiO_2 films are transparent to visible light and are sufficiently transmissive to wide area of wavelengths. Such a waveguide device can work in the same manner as described earlier

5   by using a proximity pattern to generate an evanescent field to imprint micro-patterns.

It is preferable that an exposure-mask having a proximity pattern is detachable from the light source or waveguide. This permits the exposure-mask to be cleaned or replaced when the mask

10 is contaminated with the photo-sensitive material. The light source may made of a container having a gas that emits a light when it is excited by an electron beam or a laser beam. This type of light source is convenient because there is no need for placing a physical light source inside the container to generate

15 a wave having a suitable wavelength.

The light source may also contain a gas such as Ar, Kr in the waveguide so that the gas molecules may be excited by irradiating with an electron beam being scanned. This arrangement enables to generate a high output power using a

20 relatively fine electron beam so that sufficient power can be delivered to the photo-resist film through the evanescent field. Similarly, ionic or molecular species may be substituted for a gas to generate an excited light. Exposure of a proximity pattern by exciting the ionic or molecular species with an

25 electron beam enables to generate a light for imprinting micro patterns through the exposure-mask.

Figure 3 shows an enlarged cross sectional view of a proximity pattern. A proximity pattern 12 is provided on the

21

bottom surface of the waveguide 11, and in this case, the micro-pattern on the proximity pattern 12 has line widths in a range of 50-100 nm. The height of the micro-pattern is approximately several tens of nanometers. In this case, the

5 proximity pattern 12 is either brought into contact with or placed in proximity (several tens of nm) of an object surface coated with a photo-resist film 16 on an imprint base 15, to produce an evanescent field 17 on the photo-resist film 16. Under this condition, the light trapped inside the waveguide 11 is released

10 through the evanescent field 17, i.e., an electromagnetic field 17, and exposes opposing regions 16a of the photo-resist film 16. The exposed regions 16a correspond to line widths of the high parts of the proximity pattern 12 to produce micro-patterns of line widths determined by the dimensions of the proximity

15 pattern, independent of the wavelength of the light trapped inside the waveguide 11. The exposed substrate is developed by using the normal photolithographic procedure to produce micro-patterns on the photo-resist film 16, which is used as the etch-mask to etch the imprint base 15 to produce a micro pattern

20 having line widths narrower than the wavelength of exposure light.

Figures 4A, 4B show an characteristic property of the evanescent field. The profile of the evanescent field is shown in Figure 4A. The width d of the high spots in the proximity

25 pattern 12 and the distance of separation L between the photo-resist film 16 on the wafer 15 are related as shown in Figure 12B. As the ratio of L/d becomes less than 1, a rapid release of light energy takes place from the waveguide 11 to the

22

photo-resist film 16, as shown in Figure 4B. As the proximity pattern 12 moves away from the photo-resist film 16, and the ratio L/d increases, transmission of light drops rapidly.

Figure 5 shows another embodiment of the evanescent-field-assisted imprinting apparatus. A light source 20 is comprised by a container 21 and a bottom plate 22 made of a transmissive material, and a lamp array 23 is disposed inside the container 21. Lamp array 23 can be comprised by mercury lamps, and high light energy is released towards the bottom plate 22. An exposure-mask 24 having a proximity pattern 12 is detachably attached to the bottom plate 22. An imprint base 15 with a photo-resist film 16 is placed either in close contact with the proximity pattern 12 or placed within less than 0.1 μm distance to form an evanescent field between the high structure 12a and the photo-resist film 16, and the light is transmitted to expose the corresponding sections of the photo-resist film 16, as described in the foregoing embodiments.

The construction of the apparatus of this embodiment is simplified because the exposure-mask 24 is placed close to the light source made of an array of lamps.

The mask 24 is detachable from the bottom plate 22 so that the mask 24 can be cleaned and re-used by removing any material that may adhere to the mask 24. The mask may be made disposable by using a low cost material, and also, the mask 24 and the bottom plate may be made as a single unit and not detachable.

Figure 6 shows a variation of the above photo-driven imprinting apparatus. This apparatus has a light source 20a which has a light-emitting gas 25 sealed in a space formed between

a container 21 having a window 21a and a bottom plate 22. Gases such as Ar, Kr are suitable as a light-emitting gas. An electron beam or a laser beam is irradiated through the window 21a. The gas 25 is activated when irradiated by these beams and emits a

5   light. As described in the foregoing embodiments, an evanescent field is generated when the high points of a proximity pattern 12 is brought in proximity of a photo-resist film 16. This arrangement is advantageous for making a thin light source, by removing the necessity for having a lamp array inside the

10   apparatus.

Figure 7 shows still another variation of the foregoing apparatus. The apparatus has a container 21 and a bottom plate 22, and a gas 25 such as Ar, Kr is sealed inside the container 21. A light source 20b in this case has an induction coil 26

15   on the outside of the container 21. The container 21 is made of quartz glass or a ceramic material. The induction coil 26 is supplied with a high frequency current of 13.56 MHz for example, to excite the gas 25 to generate a plasma inside the container 21, which emits a light. As shown in previously mentioned

20   embodiments, the light is used to expose the proximity pattern 12 on a photo-resist film 16 by evanescent field effect. The applied power may be 2 GHz. Microwave.

Figure 8 shows still another variation of the apparatus. The container 28 is shaped in a trapezoid profile, and an electron

25   beam generating/scanning device 29 are provided in the upper section. A light-emitting gas 25 such as Ar, Kr is sealed in the space formed between the container 28 and the bottom plate 22, as before mentioned. An electron beam generated by the

device 29 scans the space in the container to generate a light which is used to expose the proximity pattern 12 as before mentioned. Electron beam may be replaced with a laser beam.

Figure 9 shows still another variation of the apparatus shown in Figure 8. Instead of filling a fluorescent gas in the container, a light source 20d is provided inside the bottom plate 30 containing fluorescent particles 31 such as atoms, ions or molecules. For example, a fluorescent material such as rhodamines or ions 31 of Mg, Ti is contained in the bottom plate 30. An electron beam generated from the device 29 scans the space to excite the particles 31 to generate an exposure light. This method is advantageous because the exposure light is generated very close to the exposure-mask 24 having the proximity pattern, and has a high energy in a fine beam generated by a relatively fine electron beam, thereby producing a light of high energy to expose micro-patterns on the photo-resist film.

Figure 10 shows still another variation of the apparatus. Instead of the electron generating/scanning device, a micro-emitter array or a laser 32 is used, which generates a light from a surface thereof at right angle. The light source 20e irradiates the fluorescent particles 31 sealed inside the bottom plate 30 to produce a surface generated light that expose the mask 24 having a proximity pattern on the photo-resist film(not shown). Compared with the apparatus that produces spot like light sources by scanning of individual gases or particles, this apparatus produced a two-dimensional beam in one operation, making it particularly suitable for imprinting apparatus, when it is desired to have a thin structure.

Next, embodiments regarding the exposure-mask will be presented. Such masks have high portions and low portions of the micro-patterns shown in Figures 3 and 4A. However, there is a problem that light leaking occurs through the low portions

5   of micro-patterns formed on the mask, making it difficult to obtain high contrast exposure. In the following embodiments, a material of low transmissivity is embedded in the low (groove) structure of the micro-pattern.

Figures 11A through 11F show an embodiment related to a

10   method of making the exposure-mask having a proximity pattern. Figure 11A shows a quartz glass plate used in preparing a transmissive base 40 on which a photo-resist coating 41 is applied. Prebaking is applied as shown in step of Figure 11B, and electron beam exposure is carried out to produce a proximity pattern of

15   several tens of nanometers. The electron beam lithography produces line width and line spacing dimensions of 1 to 100 nm. Post-baking is carried out as shown in step of Figure 11C, and after rinsing, the exposed pattern is developed to remove the unexposed regions in the pattern, thereby obtaining an

20   exposure-mask 42. Instead of an electron beam lithography, a combination of X-rays and a reticule may be used. These methods are not subject to diffraction effect of the light so that the fabrication of micro-dimensions mentioned above is possible.

After applying a photo-resist, a soluble conductive film

25   of 10-50 nm thickness may be coated. This coating eliminates static charges produced by electron beams, and aids in producing high quality micro-patterns.

26

The surface is then irradiated with a fast atomic beam (FAB) 43, which shows excellent linearity of the etching beam and no buildup of static charges, to etch the exposed surface to produce micro-patterns having 10-50 nm high and low structures on the

5   proximity pattern 12, to be used for the micro-pattern fabrication on a photo-resist film through the evanescent field as shown in Figure 3. The use of FAB for exposure enables to produce micro-patterns, having a high aspect ratio and sub-wavelength dimensions, on a substrate. It is preferable that

10   FAB is generated by a parallel plate type source so that a large area can be exposed using a particle beam of a highly linear penetration behavior.

In this embodiment of the method of producing an exposure-mask, because a material of low transmissivity is

15   embedded in the grooves, the following step is further carried out. As shown in step of Figure 11E, a metal film 45 such as Al, Ag or Au is vapor deposited. And, as shown in step of Figure 11F, chemical mechanical polishing is applied to produce a flat surface, to produce a proximity pattern having the grooves filled

20   with a low transmissivity metallic material 45a at low structures.

Exposure-mask made by such a process forms evanescent field on the photo-resist film only at high structures of the pattern so that light leaking from the low structures is eliminated to

25   enable high contrast exposure, thereby performing high aspect ratio micro fabrication in the etching of micro-patterns.

Figures 12A-12E show a method of making the exposure-mask in a variation of Figures 11A-11F. In this method, embedding

27

of low transmissivity material is carried out by using ion exchange process. A glass plate of high transmissivity containing Na is used, and the Na ions are replaced with Ag ions to fill in the grooves. First, a resist pattern is produced on
5   the glass substrate, the steps A, B and C are the same as before.

As shown in step of Figure 11D, after making a resist pattern 42, the resist pattern side of the plate 40 is immersed in a solution containing $AgNO_3$, for example, and the opposite side is immersed in a Na containing solution, and the two sides are
10   connected to a dc or ac source. Na ions in the glass plate is replaced by the Ag^+ ions in this process, and light transmissivity through the low structure is diminished. Those regions of the glass plate covered by the resist material has the original transmissive property, so that differential transmissivity is
15   produced, caused by the low structures having the blocking material 46 and high structures of high transmissivity. As shown in step of Figure 11E, the resist film 42 is removed to produce a proximity pattern having a flat surface and a blocking material 46 embedded in the grooves. As before mentioned, high contrast
20   exposure and other benefits are performed.

Such a structure may be produced by ion injection in local low structures to produce a structure having differential transmissivity.

Figures 13A-13E are another variation of a method for making
25   the exposure-mask. As shown in step of Figure 13A, a metal (conductive) film 48 such as Cr, Al is deposited to a thickness of 10-50 nm on a transmissive base 40 such as quartz glass. A resist film 41 is coated and the base 40 is prebaked, as shown

28

in step of Figure 13B. And, a proximity pattern is produced by exposing the resist film to electron beams, and after rinsing and post baking as shown in step of Figure 13D, a resist pattern 42 is produced.

5   Using the resist pattern 42 as the exposure-masking for FAB to expose the base to produce a two-dimensional pattern 48a of metal film on the base 40. This mask can be used as the mother mask, and enables to mass produce replicated proximity pattern produced by hot pressing on a plastic resin material of a suitable

10   transmissivity.

Fast atomic beam is advantageous because of no buildup of static charges when fabricating insulating materials, and eliminate the problem of dispersion caused by electron particle rebounding, thereby enabling to utilize linearity of the etching

15   beam to produce superior fabrication. Micro-patterns having line widths and line spacings in a range of several tens of micrometers can thus be produced. Spacing between the line patterns can be larger than the wavelength of the exposure light.

According to the method of imprinting micro-patterns can

20   be produced on a metal film deposited on a glass base using FAB, it can be used directly as a mask in the process for making general integrated devices such as LSI devices.   In such cases, micro-patterns need not to be limited to sub-wavelength dimensions, and dimensions larger than the wavelength of the

25   light are of course acceptable when required.

As explained above, the present method of making a proximity pattern enable to economically produce a compact apparatus.

Also, the exposure-mask having the proximity pattern can produce high contrast exposure because of differential transmissivity so that the advantage of evanescent field exposure method can be fully utilized.

5   Figures 14A through 14E show an embodiment related to a method of evanescent-field-assisted imprinting. A base 51 is prepared by coating the surface with a first resist material 52 and a second resist material 53, as shown in step of Figure 14A. The base 51 may be a semiconductor material such as Si, GaAs or

10   an insulator such as SiO_2. The second resist material 53 is coated to a thickness of about 500 nm. The first resist material is coated to a thickness of less than the wavelength of the light and preferably less than the minimum size of the proximity pattern, approximately 30-50 nm, and should have a high responsivity to

15   the exposure light used to generate the evanescent field. For example, first resist layer 52 is polyimide and second resist layer 53 is a normal polymeric photo-resist.

Exposure is carried out as in step of Figure 14B. Exposure-mask 56 having a proximity pattern is placed in contact

20   with or in proximity (at a sub-wavelength distance) of the first resist layer 52. Light 57 is radiated from the opposite side to the proximity pattern 55 on the mask   56 under total reflection conditions, and evanescent fields are produced between the proximity pattern 55 and the first resist layer 52, to transmit

25   the light 57 and exposes the field-affected regions 58 of the first resist layer 52. In this case, the widths of the pattern 55 should be several tens of nanometers so that the patterns produced on the first resist layer 52 will exhibit narrow widths

30

corresponding to th proximity pattern 55. Therefore, the narrow width patterns can be imprinted to be less than the wavelength of the exposure light.

As described above, light transmitted through the evanescent field has low power and is susceptible to dispersion, but the patterns on the first resist layer 52 is made so as to be less than the minimum size of the pattern 55, so that the first resist layer 52 can be exposed to its total depths and horizontal dispersion is eliminated. The pattern on the exposure-mask 56 is clearly imprinted on the first resist layer 52. The second resist layer 53 is treated to be non-responsive to the processing light, by heat treatment and the like, so that the light would not pass through the evanescent field and the first resist layer 52 to expose the second resist layer 53.

Next, as shown in step of Figure 14C, the first resist layer 52 is developed by a photo-process, thereby leaving the exposed regions 52a of the first resist layer 52 and removing the unexposed regions of the first resist layer 52, and a resist pattern 52a is thus produced. This first resist pattern 52a has very thin film thickness, and is exposed uniformly in the depth direction so that a sharply defined pattern to duplicate the proximity pattern is produced. As mentioned above, because the second resist layer 53 has been heat treated during the process of exposure-masking, it is not affected during the development process of first resist layer 52.

Next, as shown in step of Figure 14D, FAB 59 is radiated through the resist-mask 52a to etch the thick second resist layer 53. Fast atomic beam may be produced from gases such as SF_6, CHF_3,

to etch the structure. The material of the first resist pattern 52a is difficult to be etched while the material of the second resist layer 53 is easily etched, so that the thick resist material 53 is partially etched away. Fast atomic beam is made of electrically neutral particles, such that charge repulsive force is ineffective to generate highly linear beams. Also, there is no charge accumulation on electrically insulating materials, only vertical etching is performed and no horizontal dispersion occurs. For this reason, it is possible to produce a high aspect ratio through the thick second resist layer 53 using the thin resist pattern 52a as the etch-masking.

Next, as shown in step of Figure 14E, FAB 59a is radiated to etch the base 51 using the resist pattern 53a formed by using the second resist layer 53 as the etch-masking. The FAB used in this step is chosen from a gaseous species so that the etching speed is high against the etching object, base 51, and is slow against the resist pattern 53a. Thus, the two processes can be performed concurrently, in which the resist pattern 53a is hardly etched while the unshielded base 51 is etched.

The properties of the FAB have been described earlier, so that etching proceeds in the depth direction while the lateral direction is hardly etched to easily produce micro-patterns of high aspect ratios in the base 51. When the pattern of several tens of nanometers in the first resist layer 52 is imprinted through the evanescent field, the same pattern widths are maintained for the thick resist pattern 53a while the same pattern width is maintained for the groove pattern 51a on the base 51.

32

Figures 15A through 15F show a variation of the method shown in Figures 14A through 14E, and the structure on the base is a three layer structure. The first photo-resist film 52 is photo-sensitive and has a thickness of several tens of nanometers, the second resist film 53 is not photo-sensitive and has a thickness of 500 nm, and the third resist film 54 is made of a metal thin film such as Cr, Ni, Al and has a thickness of 100 nm. The base 51 may be Si, GaAs or SiO_2 as mentioned earlier. Using an exposure-mask 56 having a proximity pattern 55, the top resist layer 52 is exposed through the evanescent fields, as shown in step of Figure 15B. The top resist layer 52 is sub-wavelength thickness and preferably about the same thickness as the minimum dimension of the pattern 55, therefore sharp exposure can be obtained.

As shown in step of Figure 15C, the first resist pattern 52a is developed photo-lithographically. Next, as shown in step of Figure 15D, FAB 59, is chosen from gaseous species to carry out etching of the second resist film 53 so that etching is slow against the first resist pattern 52a but fast against the second resist film 53. Gaseous SF_6 is suitable for the FAB. Next, as shown in step of Figure 15E, using the second resist pattern 53a as the etch-mask, the metal film 54 is etched. FAB 59b in this case also acts slowly against the resist pattern 53a but fast against the metal film 54. Gaseous Cl_2 is suitable for the FAB.

As shown in step of Figure 15F, using the metal pattern 54a as the etch-mask, the base51 is etched. This etching can be performed as above by FAB 59a or by a gas plasma. Because a highly etch-resistant film such as the metal film 54a is used for

protecting the base 51, therefore, even higher aspect ratios can be fabricated on the base 51.

Figures 16A through 16F show a variation related to a method of the evanescent-field-assisted imprinting. In this method,

5   resist pattern fabrication and liftoff method are combined. As shown in step of Figure 16A, a base 51 such as GaAs, Si, SiO_2 or glass substrate is prepared, and a thin photo-resist film 52 of 30~50 nm is coated. As shown in step of Figure 16B, an exposure-mask 56 having a proximity pattern 55 is placed in

10 contact or in proximity at a sub-wavelength distance with the resist film 52. By radiating a light from the back of the mask 56, evanescent fields 58 are produced between the pattern 55 and the resist film 52, which is selectively exposed according to the micro pattern 55. As before mentioned, because the resist

15 thickness of the film 52 is about the same as the minimum dimension of the proximity pattern, very sharp image of the pattern 55 is produced.

As shown in step of Figure 16C, unexposed regions of the resist film 52 are removed to form a resist pattern 52a. After

20 rinsing and post baking, a metal film 54 is deposited as shown in step of Figure 16D. The metal film may be Cr, Al, Ni or W, and 30~50 nm thickness is suitable. Metal film is generally produced by vapor deposition but electroplating, sputtering, CVD or MBE can also be used.

25 As shown in step of Figure 16E, the resist pattern 52a is dissolved, then the metal film on the pattern 52a is also lifted off to leave behind a metal film pattern 54a on the base 51. As shown in step of Figure 16F, a gas-based FAB 59c of slow etching

34

speed against the metal pattern 54a and fast etching speed against the base material is chosen to perform etching. The gas may be a mixture of Cl_2, SF_6, CHF_3 and Ar. This procedure allows slow etching of metal film pattern 54a and fast etching on

5   semiconductor material of the base 51, and high aspect ratios can be produced using the FAB that is highly linearly radiated.

In this embodiment, also, exposure is performed through the evanescent field on the thin resist film to produce sharp exposure, and the liftoff effect is used to imprint the resist pattern on

10   the metal film, and used to protect from FAB so as to perform deep etching on the base, thereby imprinting fine patterns of sub-wavelength dimensions through the evanescent field to produce structures of high aspect ratio on the substrate such as silicon.

15   In the foregoing embodiments, on top of the thin resist film for evanescent field exposure, a thermo-hardening material (thermosetting polymeric resins) may be coated thinly. This improves etching resistance against FAB for resist pattern after photo-lithographic development, and improves selective etching.

20   Micro-patterns can be produced not only on Si, GaAs, SiO_2 but other materials such as ceramics, glasses, alloys.

Also, the thin protective film for the base material is not limited to the photo-resist or metal film, and other various resins or inorganic material can be used, if the substance has

25   imprinting ability and etching resistance.

The present invention allows fabrication of micro-patterns of high aspect ratios and of sub-wavelength dimensions on a substrate.

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Figures 17A through 17D show an embodiment related to a method of making an exposure-mask for the evanescent-field-assisted imprinting apparatus.

As shown in step of Figure 17A, a mother mold 61 having micro-patterns of sub-wavelength dimensions is prepared. The mother mold 61 is made by metal material. A light transmissive mask material 63 is heated to be molten liquid and poured into a mold 61, as shown in step of Figure 17B. The material 63 is such as glasses, resins (PMMA), or plastics. Next, as shown in step of Figure 17C, a press 65 is used to press the mask material 63. In this step, the molten liquid of the mask material 63 infiltrates into the micro-patterns of the mother mold and after cooling in the mold, a proximity pattern 62 of the mother mold 61 is accurately reproduced. As shown in step of Figure 17D, the cooled masking material 63 is separated from the mother mold 61 to produce an exposure-mask 63 having a proximity pattern 62a. Separation of the mask 63 from the mother mold 61 is easily carried out because the metal mold and polymeric duplication material have different thermal expansion properties, and the duplication material is poured in hot and molten state, and is separated after the mold has been cooled and the mask 63 has been cooled to be solid.

Figures 18A through 18D show an embodiment related to making a mother mold. As shown in step of Figure 18A, a photo-resist film 67 is coated on a metal material 61a. The metal material 61a may be stainless steel (Ns-P/SUS). Next, as shown in step of Figure 18B, direct electron beam exposure is carried out to produce an exposed pattern 67a. Electron beam is free from

36

wavelength limitation of optical light, so that micro-patterns of sub-wavelength dimensions can be easily produced. Next, as shown in step of Figure 18C, the surface is developed photo-lithographically, and exposed regions 67a of the resist film 67 are removed to produce a resist film pattern 67b. The resist film pattern 67b is a proximity pattern directly formed by the electron beam.

Next, after rinsing and post baking to increase tolerability of the resist film pattern 67b, and as shown in step of Figure 18D, using the resist film pattern 67b as an exposure-mask, the metal base 61 is fabricated by etching. The etching fabrication is most suitably carried out by FAB. Particularly, a parallel plates FAB source can generate highly linear beam and free from beam dispersion caused by charge accumulation so that etching fabrication of high aspect ratios can be carried out on the metal base 61 using the exposure-mask made of the resist film pattern 67b. This process thus produces a mother mold 61 of a metal material having a proximity pattern 62.

Figures 19A through 19E show an embodiment related to a method of making the duplication mask having the proximity pattern. A metal mother mold 61 having an original proximity pattern 62 is coated with a soluble thin film 66. The thin film is water soluble, and is used to separate the mask from the mold 61. And, as shown in step of Figure 19B, a molten transmissive mask material 63 is heated to be molten state, and poured into the mold 61, and as shown in step of Figure 19C, a roller 68 is used to press the mask material 63 to infiltrate to all the corners of the pattern 62. The mold is cooled after then, and an

imprinting pattern 62a of the original proximity pattern 62 is formed on the duplication mask material 63.

Next, as shown in step of Figure 19D, it is immersed in water 70 in a container 69, the soluble film 66 is dissolved in water 70 so that the duplication mask 63 having proximity pattern 62a is separated from the mother mold 61. And, as shown in step of Figure 19E, a duplication proximity pattern 63 having the proximity pattern 62a is produced.

Figures 20A through 20E show a variation related to a method of making the mother mold. First, a base 72 of Si is prepared to have a thin film of SiO_2 73 formed thereon, which has a thickness of 0.1-5 μm. A resist film 74 is coated on the film 73 to a thickness of 10-100 nm. And, as shown in step of Figure 20A, direct electron beam exposure is performed to form a proximity pattern. Different than optical light, electron beam is not subject to diffraction effects, so that micro-patterns of sub-wavelength dimensions, less than 100 nm, can be produced by exposing with an electron beam. Exposed regions 74a of the resist film 74 are removed by photographic processing, and a proximity pattern 74b made of the resist film is produced. After rinsing and post baking to improve tolerability of the resist film, using the resist film pattern 74b as the exposure-mask, FAB is radiated to etch the SiO_2 film. This process produces a proximity pattern 73a imprinted on the SiO_2 film 73. Particularly, a parallel plates FAB source generates highly linear beam and free from beam dispersion caused by charge accumulation so that etching fabrication of high aspect ratios can be carried out on

the SiO_2 film using the exposure-mask made of the resist film pattern 74b to produce a proximity pattern 73a.

Next, as shown in step of Figure 20D, a metal film 75 such as Cr, Al, Ag, W, Mo is produced by sputtering, CVD, MBE, or vapor deposition technique. Because the process used is a vapor phase process, the groove patterns 73a are filled accurately with the metal film to reproduce the fine pattern 75a made of a metal film 75 accurately. And, as shown in step of Figure 20E, SiO_2 film 73 is dissolved in HF solution to separate the metal film 75 from the base 72. The metal film 75 has the proximity pattern 75a imprinted on, so that the metal film can be used as mother mold for mass production. Also, instead of the metal film 75, glasses, resins such as polyimide, plastics can be used with sputtering, vapor deposition or CVD. In addition to vapor deposition methods such as sputtering, molten material may be coated. In any case, by removing the SiO_2 film, a mother mold having a proximity pattern imprinted on such materials can be produced.

The mother mold can be used to mass produce exposure-mask by a method such as Figures 17A-17D or 19A-19E, and mass produced mask can be applied for the imprinting technique of evanescent-field assisted exposure to produce micro-patterns of sub-wavelength dimensions on LSI devices, and so on. The duplication masks are easily mass-produced and production cost become lower, and can be used as disposal goods.

In manufacturing of duplication mask having proximity pattern, the technique to use a semi-molten SiO_2 material to be polymerized on a quartz glass or plastic surface may be used, and this molten SiO_2 material is pressed by a metal or other kind

39

of mold having a proximity field exposure pattern so that the pattern transfer may occur in a semi-molten state of the material. After this the SiO_2 material is polymerized and the mother mold is removed. Various material may be used to produce mother mold

5   and mass produced exposure-mask, so that particular advantages may be offered by each material.

As explained above, duplication exposure-mask having the proximity field exposure pattern can be readily produced using the various techniques disclosed above. Thus,

10   photolithographic technique can be applied in conjunction with the evanescent-field assisted imprinting of micro-patterns using a mass-produced proximity patterns to imprint micro-pattern even on LSI devices.

Figures 21A through 21D show an embodiment related to a

15   method of imprinting micro-pattern of a template for an object. As shown in step of Figure 21A, an imprint template 111 having a micro-pattern 112 of sub-wavelength dimensions of the exposure light is prepared. The imprint template 111 may be made of a metal, and the micro-pattern is comprised by line widths and

20   depths of several tens of nanometers, for example. However, the line widths and depth may be larger than wave length of the light. The imprint base 113 on which the micro pattern of the template 111 is imprinted, has a resist film 115 coated on the surface thereon. The imprint base 113 may include metals such as Al,

25   Ni, Ag, Au, W, Mo, SUS, yellow brass, or an inorganic material such as Si, SiO_2, Ni-P, DLC (diamond like carbon), glasses, quartz glass, a resin material such as plastics, F-containing polymers, polyimide, PMMA.

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As shown in step of Figure 21B, the micro-pattern 112 on the imprint template 111 is made to contact the resist film 115 coated on the imprint base 113 and is pressed. This process forms a duplicated pattern of the micro-pattern 112 on the resist film

5   115. Imprinting on a polymeric material such as resist film is affected by its hardness, for example, if the viscosity is too low, imprinted shape is brittle, and if it is too high, the corners are rounded so that high aspect ratios are difficult to be achieved. Proper control is important in micro-pattern

10   production.

The state of the imprint template 111 after the removal of photo-resist film 115 is shown in step of Figure 21C. After post baking and others, tolerability of the resist film is improved. And, as shown in step of Figure 21D, FAB irradiation is performed.

15   FAB is an electrically neutral beam, and in particular, parallel plate type FAB has a characteristic of high beam linearity of the etching beam so that the imprint base 113 can be etched to a high aspect ratio.

Figures 22A through 22D show a variation of the technique.

20   In this case, the imprint base 113 is pressed by a roller 117. This technique can overcome high/low structures or curved structures of the imprint base. Other steps are the same as those shown in Figures 21A through 21D.

Figures 23A through 23D show another variation of

25   micro-pattern imprinting. In this case, the template 120 is a flexible material. As shown in step of Figure 23A, the imprint base 113 is coated with a resist film 115, which is facing separated from the micro-pattern 112 on the template 120. As

shown in step of Figure 23B, a roller 117 is used to press on the template 120 to transfer the micro-pattern 112 on the template 120 to the resist film 115 on the base 113. This is used as exposure-mask for FAB irradiation to etch the imprint base 113,

5   and as shown in Figure 23D, a micro-pattern 113a is formed on the imprint base 113 as in the foregoing embodiment. In this embodiment, flexibility of template 120 is an advantage so that even if the imprint base 113 is curved, micro-pattern 112 can be imprinted.

10   Figures 24A through 24D show another variation of a method for micro pattern imprinting. A template 121 is a roller having the micro-pattern on its outer peripheral surface. As shown in step of Figure 24A, an imprint base 113 is prepared by coating a resist film 115, and as shown in 24B, the roller 121 is pressed

15   and rotated on the resist film 115 on the imprint base 113 to imprint the micro-pattern. Subsequent steps in Figures 24C, 24D are the same as those in foregoing embodiments. This technique is advantageous when the imprint base 113 has curvatures.

Figures 25A through 25D show another variation of a method

20   for micro pattern imprinting.

As shown in step of Figure 25A, an imprint template is a roller 21a having micro-patterns in the axial direction. As in the above embodiment, an imprint base 13 with a resist coating 15 is prepared, in this case, the imprint base 13 is quartz glass.

25   As shown in step of Figure 25A, the micro-patterns are replicated on the resist-film 15 by using the roller 21a which is pressing and rotating thereon. And, as shown in step of Figure 25C, FAB is used to fabricate for etching the resist film 15 and the imprint

base 13 underneath. As shown in step of Figure 25D, micro-patterns formed on the resist film 15 are imprinted on the imprint base 13.

In this case, spacing A and depth B of the micro-patterns can be fabricated to be about 0.1~100 μm. Micro-patterns fabricated on quartz glass can be used most suitably for making diffraction lens, pickup lens and Fresnel lens. Irradiation conditions for FAB are using SF_6 gas, discharge voltage 3 kv, discharge current 30~50 mA, beam diameter 80 mm, cooling temperature for substrate base -30~-50 °C, and fabrication speeds of 100~300 Angstrohm/min can be produced. Micro-patterns of the roller may be made as a unit with the roller or may be prepared separately. Micro-patterns on the resist film may be replicated by using a constant pressure, which is given by the roller operated by any type of suitable jig.

Figures 26A through 26D show a variation of an embodiment shown in Figures 25A through 25D. As shown in step of Figure 26A, the spacing of the micro-patterns fabricated in the axial direction on the roller 21b are varied, and as shown in step of Figure 26D, micro-patterns of the roller 21b are replicated on the imprint base 13. Other than this difference, this embodiment is same as shown in Figures 25A through 25D. Figure 27 shows an embodiment fifteen of a method of micro-pattern imprinting. In this case, instead of the resist film, polymerizable film 122 is used. As shown in step of Figure 27A, an imprint template 111 having a micro-pattern 112 of sub-wavelength dimensions is prepared and a semi-solid polymerizable film (SiO_2) 122 is coated, and an imprint template 111 is pressed against the film 122. The

43

imprint template 111 is separated to produce an imprinted pattern 122a as shown in step of Figure 27C. This semi-solid polymer film 122 is heated to polymerize the film 122 to film 122b. It is important to control polymerization condition to prevent degradation in property due to improper heating. The polymerized film 122b can be fabricated by an energetic beam such as FAB, and can withstand FAB etching as shown in step of Figure 27E to produce micro-patterns of high aspect ratios.

Figure 28 shows sixteenth embodiment of a method of micro-pattern imprinting. As shown in step of Figure 28A, a water soluble thin film 124 is coated on the surface of a resist film or polymer film 113. Thickness of the thin film is 10-50 nm, and is thinner compared with the thickness 10-100 nm of resist film or polymer film 113. And, as shown in step of Figure 28B, the imprint template 111 is pressed against the resist film 113 to imprint the micro-pattern. And, as shown in step of Figure 28C, it is immersed in water. The thin film 124 is dissolved in water, and the imprint template 111 can be separated easily from the resist pattern side to prevent damaging the pattern formed on the resist film is damaged. Step 28D is the same as the other foregoing embodiment.

Figure 29 is a embodiment seventeen of a method of micro-pattern imprinting.

As shown in step of Figure 29A, a metal template 111 having micro-patterns smaller than the wavelength is prepared. As shown in step of Figure 29B, an imprinting material made of an imprinting material 113x such as glasses, resins (PMMA) and plastic material is poured in a molten state on an imprint

template 111. Next, as shown in step of Figure 29C, a press 126 is used to apply a pressure on the imprinting material 113x. The imprinting material fills the grooves in the pattern on the imprint template 111 and when it is cooled, a micro-pattern 112

5 is accurately imprinted to the imprinting material 113x.

Next, as shown in step of Figure 29D, cooled material 113c is separated from the imprint template 111 to produce an imprinting material 113c having a micro-pattern completed. When separating, if the imprint template 111 is metallic and the

10 imprinting material is glass or resin, thermal expansion coefficients are different, and especially because the imprinting material fills in a heated state and solidifies after cooling, separation is achieved easily.

Figures 30A through 30E shows an embodiment of a method of

15 micro-pattern imprinting. A soluble film 128 is coated on a metallic template 111 having a micro-pattern 112. The soluble thin film 128 is water soluble and is used for separation purpose. As shown in step of Figure 30B, heated and molten material 113x is poured into the metal template 111. Next, as shown in step

20 of Figure 30C, a roller 117 is used to press the molten material 113x into every corner of the micro-pattern 112. After cooling, an imprint pattern 113c of the solid micro-pattern 112 is formed on the imprint material 113x.

And, as shown in step of Figure 30D, the imprint template

25 111 is immersed in water to dissolve the coating material 128 in water 130, and the imprint pattern 113c is separated from the template 111, and thereby making an imprint pattern 113c having the micro-pattern 112 imprinted from the imprint template 111.

Figures 31A through 31D are an embodiment related to a method for making templates. As shown in step of Figure 31A, a metallic material 111 is coated with a resist film 131. Stainless steel (Ns-P/SUS) is suitable for the metallic material. Next, as shown

5   in step of Figure 31B, micro-pattern 131a is fabricated directly on the imprint material 111 using an electron beam. Electron beam direct exposure method is not affected wavelength limitation as is the optical light, micro-patterns of sub-wavelength dimensions can easily be fabricated directly. Next, as shown

10   in step of Figure 31C, the resist film 131 is photo-lithographically developed, and all material excepting the exposed section 131a is removed, thereby producing a resist pattern 131b formed directly by the electron beam.

Next, rinsing and post baking are applied to improve

15   tolerability of the resist pattern 131b, and next, as shown in Figure 31D, resist pattern 131b is used as an exposure-mask to etch the metallic material 111, using FAB, and in particular, parallel plate type FAB has high beam linearity of the etching beam and no dispersion caused by accumulated static charge, so

20   that an imprint template 111 having micro-patterns with high aspect ratios can be produced using an exposure-mask 131b.

Above example is only one case, and instead of electron beam, X-ray beam can also be used. Instead of FAB, plasma etching may also be applied. The material for template may be a silicon,

25   ceramic or resin material instead of a metallic material.

As described above, the technique of fabricating LSI of sub-wavelength line width and spacing (0.1 μm or less) is not yet established, and even the resist pattern making is difficult

46

in some cases. Normal optical photolithography processes are limited by the wavelength effect of the exposure light. Electron beam exposure technique has no wavelength restrictions, but the scribing method is not suitable for mass production, resulting

5   in high cost. Although the X-ray exposure method is similarly not limited by the wavelength effect, and high precision pattern making is fundamentally possible, but in practice, there are many problems, and it is difficult to be incorporated into a practical production line. With respect to etching fabrication, plasma

10 method suffers from poor directionality of the energetic particle beam, and because the resist materials are poor conductors, which leads to non-uniform distribution of electrons and consequently to poor fabrication.

Figures 32A through 32D show an embodiment related to a

15 method of making LSI devices. This method uses a template having micro-patterns of sub-wavelength dimensions and imprint the pattern directly on a resist surface coated on a semiconductor wafer. As shown in step of Figure 32A, a template 19 having micro-patterns of sub-wavelength dimensions is prepared. This

20 template 19 is made of a metal, and the micro-pattern includes structures having depths and widths in a range of several tens of nanometers. An imprint base 15 is coated with a resist film 16. The template 19 may include metals such as Al, Ni, Ag, Au, W, Mo, SUS, yellow brass, or an inorganic material such as Si,

25 SiO_2, Ni-P, DLC (diamond like carbon), glasses, quartz glass, a resin material such as plastics, F-containing polymers, polyimide, PMMA. Photo-resist may be replaced with a polymerizable semi-solid material that can imprint exposure-

47

structures by being in contact with the template and produces tolerability for etch-mask by thermal treatments.

And, as shown in step of Figure 32B, the pattern on the template 19 is made to contact the resist film 16 on the imprint
5 base 15 and pressed to produce an imprinted pattern 16a on the resist film. Imprinting on a polymeric material such as resist film is affected by its hardness, for example, if the viscosity is too low, imprinted shape is brittle, and if it is too high, the corners are rounded so that high aspect ratios are difficult
10 to be achieved. Proper control is important in micro-pattern production.

Step of Figure 32D shows separation of the resist pattern 16a from the template 19. After post baking and the like to improve tolerability, FAB irradiation is performed as shown in
15 step of Figure 32D. FAB is an electrically neutral beam, and in particular, parallel plate type FAB has highly linear etching beam so that the imprint base 15 can be etched to a high aspect ratio.

By following above steps, the micro-pattern can be imprinted
20 efficiently on the resist film 16, and the imprinted pattern 16a is used as etch-mask to perform etching of insulation films and conductive films on the wafer as well as the wafer itself. The method eliminates exposure apparatus, and equipment cost can be reduced significantly.

25 Figures 33 and 34 show examples of cross sectional cell structure of LSI, especially the DRAM structure. A capacitor section 220 is comprised by an oxide film 224 intervening between the silicon base 223 and the polysilicon film 222. A transistor

48

section 221 is a MOSFET comprised by a gate electrode 225 of polysilicon operating through the thin oxide film 224, located between diffusion layers 226 for source/drain fabricated on silicon substrate 223. Wiring line 227 of metallic material such as Al contacts the n* diffusion layer 226 through a contact hole 228. In this type device structure, the need for size reduction is focused particularly on the width of gate electrode 224, the thickness of thick oxide layer 224 and the width of contact hole 228. It is preferable that the size of these regions should be less than the optical wave length limits at around less than 0.1 μm.

Figure 34 shows a cell structure of another DRAM. In this structure, the capacitor section 220 has a vertical cell configuration disposed on top of the transistor section 221. The capacitor section 220 is comprised by an insulator film 233 sandwiched between the upper electrode 231 and the lower electrode 232. Structure of the transistor section 221 is the same as that shown in Figure 33. In this device, word shunt lines 234 are placed on the insulation film 235.

The width of circuit patterns in LSI devices is becoming narrower every year, and the minimum line width in 1Gbit memory will be about 0.2 μm and decreasing yet further. Along with the need for narrower line width, demand is towards a structure of higher aspects ratios as indicated in Figure 34, and it is anticipated that, in the near future, aspect ratio higher than five will be demanded.

Fast atomic beam (FAB) is highly effective in etching fabricated structures having a high aspect ratio. Conventional

49

plasma etching presents a problem of charge accumulation on the surface of the object being etched, and in some case, insulation film can be broken by charge accumulation. In particular, it is necessary to etch thin insulation film in memory devices, and

5   if the insulation film is damaged by charge accumulation, leak current is increased and the memory device cannot work properly as its capacitance is degraded. The use of FAB, with its electrical neutrality and linear etching beam, promotes fabrication of circuit structures having a high aspect ratio,

10   without the fear of causing charge accumulation. Therefore, by utilizing the technology of evanescent field assisted exposure or stamp imprinting technique for fabricating photo-resist film to produce etch-mask to be used in conjunction with FAB, it is considered possible to manufacture micro-patterns having high

15   aspect ratios.

When such fabrication techniques become available, it would be possible to further increase circuit density in logic LSI by reducing width and line dimensions, thereby leading to faster processing speed. For memory devices, memory capacity per given

20   area would increase dramatically to provide high performance memory devices. Processing capabilities of microprocessor chips, which consist of logic and memory circuits, would also benefit greatly from improvements in integration density.

Next, applications of the present technology to recording

25   medium for magnetic-optical discs and head devices will be presented.

Figures 35A through 35D show an embodiment related to a method of making a master disc for producing recorded medium used

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in optical disc apparatus. In this case, it presupposes that an exposure-mask 240 having micro-patterns of sub-wavelength dimensions for use in proximity field exposure is already available. Such an exposure-mask 240 is installed in an exposure apparatus shown in Figure 1, for example, and light is radiated from a light source. Master disc 241 may be made of a metallic material having a resist film 242 coated thereon. The resist film 242 is made to contact with or placed in proximity at a sub-wavelength distance to generate evanescent fields 243, and the resist film 242 forms exposed regions 242a, thereby imprinting the micro-pattern on the mask 240, as shown in step of Figure 35B. Unexposed regions are removed by photo-lithographic developing and post baked to improve tolerability, and as shown in step of Figure 35C, FAB irradiation is performed, with the use of etch-mask 242a, as explained earlier, to produce a master disc having a micro-pattern 241 imprinted thereon, as shown in step of Figure 35D. FAB has high linearity of the etching beam and is comprised by electrically neutral particles so that structures having a high aspect ratio can be produced by FAB etching. This process produces recording signals (bits) on the surface of the master disc 241. Minimum size of the bit or track width is sub-wavelength at about 0.1 μm.

Figures 36A through 36E show an embodiment related to a method of making an optical recording medium.

As shown in step of Figure 36A, a master disc 241 produced by the above technique is placed so that the micro-pattern faces upwards, and is coated thinly with a water soluble thin film 244. Next, as shown in step of Figure 36B, a thermoplastic masking

51

material 245 is poured on top, and as shown in step of Figure 36C, a roller 246 is used to push the masking material 245 so as to reach into every corners of the micro-pattern. Next, as shown in step of Figure 36D, the disc 241 is immersed in water

5   248 to dissolve the film 244, which is removed from the disc 241. As shown in step of Figure 36E, an optical disc 245a having recording signals of sub-wavelength dimensions is completed. Using this process, optical discs having recording signals of sub-wavelength dimensions can be easily produced in large

10   quantity from the master disc.

A thin separation layer may be produced in step of Figure 36A of the above process, and dissolved in water in step of Figure 36D to facilitate separation from the mold and reduce chances of damaging the micro-pattern. However, if mold separation does

15   not pose a problem, steps of Figure 36A and Figure 36D may be omitted. Instead of using a roller to press on the thermoplastic material, injection molding process may be used to produce recorded discs.

Also, the example was based on the evanescent-field-

20   assisted imprinting technique to manufacture a master disc, but electron beam or X-ray lithographic techniques may be used in combination with FAB irradiation to produce signal patterns of sub-wavelength size.

It is preferable that a light detector 250b for use with

25   such an optical disc to be provided with a reading head shown in Figure 37 so that the tip 250a of the head 250 is a sub-wavelength dimensions. This device permits to detect recorded information represented by bit patterns of sub-wavelength size

on the optical disc 245a through an evanescent field. Also, as shown in Figure 38, recorded patterns are not limited to pit patterns produced on the recording medium, instead of the pits, signals may be represented by phase changes, brought about by

5   light radiation, that are recorded on a phase change layer 249c provided on a base 249. Such a recording medium is comprised by a phase change layer containing primarily Ge-Te-Sb sandwiched between a metallic reflection film 249a and a transparent protection film 249b formed on the base 249. Signals are

10   recorded according to transmission/reflection of incident light through the phase change layer 249c.

Such a head 250 having a micro-opening is produced by electron beam to scribe a pattern of sub-wavelength dimensions directly on a photo-resist film coated on a substrate such as

15   quartz glass or resin, and using the pattern as the etch-mask for FAB etching to produce a deep cavity.

Figure 39 shows a multi-track reading head 251 made by arranging a plurality of small heads 251a in a line that can respond to evanescent-field-assisted light transmission.

20   Therefore, such a multiple-head is able to read several tracks, containing recorded bit signals of several tens of nanometers size, concurrently.

Figure 40 shows an optical recording device comprised by a recording base 261 containing a pattern of sub-wavelength

25   dimensions to respond to light transmission and reflection, a light source 260 for incident light and a sensor section 262 placed in opposition to the pattern surface. The recorded medium 261 has recorded information comprised by micro-patterns of

50-100 nm width and 10-30 nm height. The base 262 of the sensor section has similar continuous micro-patterns and the high structures of the pattern is in contact with or placed in proximity at a sub-wavelength distance.

On the recording base 261, data are represented by "1" or "0" corresponding to presence/absence of high structures of a high/low structure, but in contrast, data in the detection section are represented by a continuously imprinted high/low structure of the micro-patterns. Therefore, the recording section records "1" where its high structure coincides with a high structure in the sensor section, and records "0" where there are no opposing high structures. Those points with "1" signals can produce evanescent-field-assisted transmission signals which are detected through the sensor section 262 in the detection section (not shown). The detection section may be connected to a fiber bundle of sharp tipped fibers of sub-wavelength dimensions to receive evanescent-field-assisted signals.

In such a recording device, the sensor section 262 and the recording section 261 are fixed in their relation positions, and has no moving parts. Therefore, this device can conveniently detect signal strengths produced by micro-patterns of sub-wavelength dimensions, and can realize a stationary-type of information reproduction device of ultra-high data capacity.

Also in the device showing in Figure 40, light is input from the back surface of the base of the recording section, and the sensor section outputs signals from its back surface, but the device may be arranged such that signals are input from the back surface of the sensor section to the recording section, and

reflected output signals are detected by the sensor section. Further, a reflection film may be coated on the back surface of the base of the recording section. Such a device can generate higher contrast signals from weak signals transmitted through
5   the evanescent fields.

Devices used to record/regenerate strength variation of optical signals in compact disc (CD), laser disc (laser disc), digital video disc (DVD) operate according to pit patterns provided in the recording section to generate variations in
10 signal strength. In DVD, blue laser (emitting at 458 nm) and krypton ion laser (emitting at 351 nm) are used to fabricate minimum pit dimensions of a 0.4 μm length and a 0.3 μm bit width, and signal strength variations are monitored by detection section based on laser and lens system. Conventionally, the disc having
15 recorded data is rotated by one signal detection section to serially read the presence/absence of pits.

Master disc for reproducing recorded medium are manufactured by photolithography. In the conventional technology, female-type master disc is produced by laser exposure
20 technique to generate pit patterns, and the cavities are treated with Ni plating and electro-forming. Consumer discs for CD, LD, DVD are produced from the master disc by injection molding.

In magnetic-optic recording devices, data recording and erasing are performed by heating above the Curie point to
25 randomize electron spins in the magnetic material and cooling in a magnetic field to align spins in the magnetic material. Heating temperature can exceed 400 °C locally. Reproduction is performed by detecting rotated polarized light components,

produced by optical magnetic interaction (Kerr Faraday effect), in the recorded magnetic layer. Therefore, a polarized light detector is used in the reflected laser detection section of the head.

5   Figure 41 shows a structure of the head section of a magnetiv-optical disc device. The head 266 has a tip opening 267 of a sub-wavelength dimensions, and also has a magnetic field generation coil 268 for generating a magnetic field for magnetizing a magnetic layer 269a of a recording medium 269, which
10   is placed in proximity of the tip opening 267. Magnetization axes generated in the magnetic layer 269a are controlled over a region of sub-wavelength dimensions by controlling the interaction of the evanescent field 263 and the magnetic layer 269a by the light input through the tip opening 267. Conversely,
15   recorded data are read by detecting power of input light affected by the differences in the magnetization axes.

The recording medium is comprised by a base 269 and a magnetic layer 269a formed thereon and a protective film 270. The protective film has micro-roughness to provide a friction
20   reducing effect when the disc is placed at less than 50 nm distance to the head.

The magnetic layer 269a may be impressed with digitized signals so that one pit corresponds to one bit to provide higher contrast images.

25   Although certain preferred embodiments of the present invention have been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.